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BIDIRECTIONAL BIPOLAR STATIC INDUCTION DEVICE

"paragraph 0001". The invention relates to microelectronics and more particularly to bidirectional bipolar static induction devices: transistor and transistor-thyristor (transistor, which can be latched) with elements of a control circuit. Any device, according to the present invention can be latched. However, if a thick channel drain electrode have been connected to an ordinary channel drain electrode and if the latch current of the device exceeds the maximum permissible constant current, such device can be considered as the device without latching, i.e. the transistor.

"between paragraph 0001 and 0002". There exists a static induction type semiconductor device is used as a power transistor. It is of the surface gate type and is used for providing a high current density. The static induction type semiconductor device provides a plurality of a small source regions surrounded by a gate region. According to this structure the channel region beneath the source region becomes small, thereby increasing the stored carrier density and enabling a large main current to flow when using a small gate current, thereby achieving a high current amplification ratio. A thin insulating film provided on the surface of the n+-source region operates as a tunnel-oxidized film, thereby enabling electrons to be injected into the source region but preventing the positive holes from being drawn out. Therefore, as the consumption of positive holes store in the channel region decreases, a sufficiently large source current is allowed to flow even if a further smaller gate current is injected, thereby further increasing the current amplification factor[1]. The drawbacks of the transistor are that it cannot operate on circuits of alternating voltage and that the current density is insufficient.

There exists a vertical JFET, in which a gate and a channel are formed by the implantation of an impurity in a doped epitaxial layer through mask – a doped polysilicon [[drain]] source electrode [2]. The method provides forming of the transistor with channel thickness equal about 10.sup.-7 m. The drawback of the transistor is that it cannot operate on alternating voltage circuits.

"paragraph 0008. The offered transistors and transistor-thyristors can be applied for ~~production, transfer~~ generation, transmission and use of electric energy within a very broad range of power: from the control of electrical soldering to the control of most powerful turbogenerators and thermonuclear stations. They are effective for designing electronic transformers, power supply units, and ~~"flexible transfers of alternating current"~~ controllable power transmission lines. In the latter case transistor-thyristors can be connected in series, which will allow to easily create high voltage system with operating voltage 10.sup.6 V and more with a control with light signals or by wireless. These transistors can be most widely used in the devices aimed at defending people from electric shock. They can also be used in systems with the unipolar power supply transmitting energy in both directions – both from a source to a load (resonator) and from the load to the source. It will make it possible to increase circuit efficiency with the voltage drop between a drain and source of the open transistor as a rule not exceeding 0.5 V and, if necessary, it can be highly close to zero.

"paragraph 0010". Though the structure of the transistor is symmetric the operating duty of the channel that is near the drain of the transistor essentially differs from the operating duty of the channel that is near its source. The electrical field reduces the concentration of holes in the former and increases their concentration in the latter. Owing to this, the hole concentration along an axis perpendicular to surface is trapezioidal in zero approximation. It puts certain restrictions both on the design parameters of [[BSIT]] BBSIT and on designing of circuits in which these transistors are applied. Introduced in the structure the thick channel provides increasing of operating current (without latch). A threshold voltage of the thick channel is lower than that of the ordinary channel. Algorithm of control of the offered transistor under typical circumstances is more complicated than that of the transistor described above [3]. Let potentials of the gates are equal to potentials of the source and drain accordingly. The electrons flowing to the drain electrode can cause emission of the holes from the gate, disposed near the drain. The holes flow to the gate, disposed near the source. Part of the holes flow into the channel and causes the flow of the electrons to the drain. So, there is a positive feedback in the device. Device is latched. On-voltage of the latched device is more than on-voltage of the open transistor. To prevent the feedback it is necessary to provide so that electrons might flow to the drain free. It depends both on a control circuit and on the construction of the transistor. The part of the control circuit is represented on fig.10 of the application. Electrons might flow to the drain through open transistor 113 or 123. (In the simplest variant the thick channel drain electrode has been connected to the ordinary channel drain electrode with a conductor.) The construction of the transistor provides the way for electrons to the drain through the thick channel while transistor is closed or is being switched off. The potential of the thick channel drain electrode has to be positive or zero or little negative relative to the potential of the drain electrode of ordinary channel. The high drain voltage extracts electrons from the thick channel which is disposed near the source. The potential of the thick channel source electrode has to be positive so that the thick channel is closed. (It is allowed that the potential of the thick channel source electrode might equal zero, if the threshold voltages equal approximately 0.2 volt).

When changing polarity of the applied voltage, the source and drain change places, and the potentials of the thick channel electrodes should be changed accordingly so as the transistor is to remain closed. In this case the transistor can maintain voltages up to several kilovolt depending on parameters of the lightly doped area, in the first place from the thickness and number of donors between the gates as well as from an edge termination structure. To prevent an avalanche breakdown near the edge of the substrate, to decrease on-voltage, to increase speed of response and current density one might use a rib of rigidity of definite dimentions(fig.11). The channels of the transistor have to dispose in the recess bottom. In this case the avalanche breakdown can occur on the gate boundary near the edge of the recess bottom or near the edge of the thick channel depending on the parameters.

Another voltage on the gates is about 0.8 V relatively of the source and drain which are nearby. It provides the opening of the channels and hole emission into the channels and lightly doped area. The emission of holes to the lightly doped area is followed by electrons from the transistor source which makes the hole concentration and electron concentration practically the same in zero approximation and may reach the magnitude of 10.sup.17÷10.sup.18 cm.sup.-3 and more; resistance of the transistor drops abruptly due to conductivity modulation and the voltage between the drain and source of the transistor as a rule does not exceed 0.5 V at current density ≈ 1000 a cm.sup.-2(the thickness of the substrate is decreased by etching). There is a smoothly lowering voltage on the gate which is near the source of the transistor during the switching of the transistor from on-condition to off-condition, owing to extraction. To decrease the loss of switching off the voltage on the gate which is near the drain of the transistor should be remain during the first part of time of switching off (approximately 1 us). It is ~~permitted a small~~ desirable a hole emission into the lightly doped area during first part of time of ~~switting~~ switching off (extraction out holes exceed emission into one). It is undesirable but permitted a small hole emission into one during second part of time of switching off.

"paragraph 0011". To increase operating current of the transistor (without latch), the offered [[BSITs]] BBSITs should have the channel with a low resistance. To this end, the thickness of the channels should be small and the impurity concentration near the gate should be high enough so that the electronic current flowing near the gate could not cause a large voltage drop which, in turn, could lead to emission of holes. To meet these requirements, it is desirable to grow an epitaxial layer with donor impurity concentration being about 10.sup.17 cm.sup.-3 on the surface of the lightly doped substrate having the donor impurity concentration about 10.sup.14 cm.sup.-3, and to have an equipment with higher resolution than is generally used for manufacturing other BSITs. The distance from the boundary of the epitaxial layer to the gate should be about 0.1um. The other variant – implantation of both donor and acceptor in the gate and double drive-in diffusion to provide thin layer donor impurity near the gate including the channel.On the surface of a monocristal silicon a layer of a polysilicon may be disposed that would help to form the elements of the transistor: the gate, the source, the channel and the electrodes.

"between paragraph 0011 and 0012". A solitary pulse current density ~~(without switching off by the transistor)~~ can be several times bigger, tending to 10000 a cm.sup.-2. Maximum pulse current is bigger than latch current. Auger recombination restricts the carrier density. In this case the hole concentration is approximately the same in the whole lightly doped area. The influence of diffusion currents is negligible. The offered transistors, as the transistor [3], can control power greater than any other types of transistors all over the world.

"paragraph 0013". It is desirable to dispose driver transistors on the chip above the main one. Most suitable transistors for the driver are low-voltage bipolar ~~static induction~~ mode field effect transistors. Due to a small size, they have sufficiently low resistance on-condition, high gain and high speed response to control a power transistor. Parts of the control circuit on either side of the chip can be controlled by light signals with the help of photodiodes or by wireless.

"paragraph 0019". Inventions is explained with ~~twelve~~ fourteen drawings.

"between paragraph 0022 and paragraph 0023". Fig.9 represents bidirectional semiconductor device structure (prior art).

Fig.10 represents offered transistor with a part of the control circuit (one from several variants; for illustration only).

Fig.11 represents the substrate structure with the ribs of rigidity.

Fig.12 represents the offered transistor with a part of the high voltage control circuit (one of several variants; for illustration only).

Fig.13 represents a part of the circuit of the high voltage breaker with offered transistor-thyristors (one of several variants; for illustration only).

Fig.14 represents planar view of the offered transistor suitable for sequential connection. (Scale has not been kept. One of several variants; for illustration only).

Fig.15 represents planar view of the offered high current transistor. (Scale has not been kept. One of several variants; for illustration only).

Fig.16 represents planar view of the offered transistor. (Scale has not been kept. One of several variants; for illustration only).

Fig.17 represents a power normally-off transistor structure with two lowpower normally-on channels.

"between paragraph 0023 and 0024". Bidirectional bipolar static induction transistor-thyristor fig.4 comprises lightly doped n-type substrate (area) 28, gates 29, gate electrodes 30, thick channels 31, thick channel source electrodes (n+-type polysilicon) 32, thick channel sources 70, ordinary channel sources 33, ordinary channels 34, ordinary channel source electrodes (n+-type polysilicon) 35, ordinary channel source contacts 36, thick channel source contacts 37.

Bidirectional bipolar static induction transistor fig.6 comprises lightly doped n-type substrate (area) 47, epitaxial layers 48, gates 49, gate electrodes 50, thick channels 51, thick channel sources 69, thick channel source electrodes (n+-type polysilicon) 52, thick channel source contacts 53, ordinary channels 54, ordinary channel sources 55, ordinary channel source electrodes (n+-type polysilicon) 56, ordinary channel source contacts 57, isolation 58.

"between paragraph 0025 and 0026". Bidirectional semiconductor device fig.9 comprises substrate 101, n+-type source 102, p-type base (anode) 103, p-type anode (base) 104, n+-type source 105, terminals 106,107.

Fig.10 comprises offered transistor 110, hole emission key 111, hole dischage (extraction) key 112, electron dischage key 113, amplifier with nonlinear feedback (polarity fixture) 114,115,113; hole emission key 121, hole dischage (extraction) key 122, electron dischage key 123, amplifier with nonlinear feedback (polarity fixture) 124,125,123; (transistors 111,112,113,121,122,123 – low-voltage bipolar ~~static induction~~ mode field effect transistors).

Fig.11 comprises the operation part of the substrate 131, ribs of rigidity 132, recess 133.

The ribs of rigidity increase a mechanical durability of the substrate and permit to decrease the thickness of the operation part and to improve the main performances of the transistor.

Fig.12 comprises the offered transistor 110, hole emission key 111, hole discharge (extraction) key 112, electron discharge key 113, amplifier with nonlinear feedback (polarity fixture)114,115,113; diodes 116÷120, hole emission key 121, hole discharge (extraction) key 122, electron discharge key 123, amplifier with nonlinear feedback (polarity fixture) 124,125,123; diodes 126÷130; (transistors 111,112,113,121,122,123 – low-voltage bipolar ~~static induction~~ mode field effect transistors).

If the drain voltage exceeds a threshold voltage it extracts electrons from the thick channel through the group of diodes 116÷120 or 126÷130 and prevents further increasing of the voltage on the device. Seriesly connected transistor-thyristors allow to easily create high voltage system with operating voltage 10.sup.6 V and more with a control with light signals or by wireless.

Fig.13 comprises button "start" 134, button "break" 135, ~~former~~ reformer 136, solenoid 178, transformer 137, the offered transistor-hirystors 140,145; Schottky diodes 138,142,143,147, 148,160,162,174; diodes 150÷159,164÷173; resistors 139,141,144,147,149,161,163,175,176; switch 177, mobile contact 179, immobile contacts 180÷183.

Resistors 139,141,144,147, 149,161,163,175 define boundaries of the latching.

Let the switch 177 be off. After the button "start" 134 is pushed, the ~~former~~ reformer 136 switches on the solenoid 178 synchronously with alternating voltage. The mobile contact 179 is closed to contact 183 in several milliseconds and a small current flows to the contact 182 and the transistor-thirystors 140,145 through resistor 176. In several milliseconds the mobile contact 179 is closed to the contact 182 and the transistor-thirystors 145,140. The ~~former~~ reformer 136 sends the pulse on the transformer 137 in one cycle of voltage the moment the voltage zero crossing is detected. The transistor-thirystors 140,145 are switched on and the current begins to flow through the contacts 180,179,182. In several milliseconds the contacts 179,181 are closed and the current flows to the load by the shortest way. Thus, the switching on takes place without arcing.

Let the alternating current flow to the load through the contacts 180,179 and 181. After the button "break" 135 is pushed the solenoid 178 disconnects the contacts 179,181 without synchronizing with voltage. The current flows between the contacts 180,179,182 and the transistor-thirystors 145,140 for several milliseconds. After the current zero crossing takes place the transistor-thirystors 140,145 (the lifetime of the holes has to be not very long) are switched off and the current is switched off. Thus, the switching off takes place without arcing within one cycle of voltage.

Planar view of the offered transistor fig.14 comprises source contact of ordinary channel 184, source contact of thick channel 185, gate electrode 186.

Dimentions of the different elements of the thick channel have been chosen taking into consideration an operation of the automatic control system of [[key]] keys ~~(seriesly connected transistors)~~ to remove possibility of an autogeneration. Seriesly connected transistors manufactured

accordingly fig.14 can be switched off without destroying unlike transistors manufactured accodingly fig.16.

Planar view of the offered transistor (maximum current order 10A) fig.15 comprises source contact of thick channel 187, area for gate electrode and source contacts of ordinary channels 188.

Planar view of the offered device fig.16 comprises source contact of ordinary channel 191, source contact of thick channel 190, gate electrode 189.

This construction permits to create transistor-thyristors which can be connected seriesly as well as transistors, if ordinary channel threshold voltage is low enough (There is danger of destroying seriesly connected transistors manufactured accordingly fig.16 during transistors is being switched off unlike transistors manufactured accordingly fig.14). If the leads of the thick channels have not connected said transistor can be used as tetrod, which was excepted from the application.

Bidirectional bipolar static induction transistor fig.17 comprises lightly doped n-type substrate (area) 47, n-type layers 71, gates 49, gate electrodes 50, thick channels 51, thick channel sources 69, thick channel source electrodes (n+-type polysilicon) 52, thick channel source contacts 53, ordinary channels 54, ordinary channel sources 55, ordinary channel source electrodes (n+-type polysilicon) 56, ordinary channel source contacts 57, isolation 58.

Ttransistor has created by implantation of both donor and acceptor in the gate and double drive-in diffusion to provide thin layer donor impurity (about 10.sup.12 cm.sup.-2) near the gate including the channel.

Notice of fig.2: The amended drawing have formed by me with the help of my computer. Changes are negligible.

Notice of fig.6: The amended drawing have formed by me with the help of my computer. Changes are negligible. The thick channel is disposed in the chip center.

Notice of fig.14: The amended drawing have formed by me with the help of my computer. Principled changes are absent.

Notice of fig.15: The amended drawing have formed by me with the help of my computer. Areas under contact pads where thick channels have concentrated, have disposed more uniformly on the chip.

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P.S. The application was written during about a month. The pulse operating duty, control circuits and constructions of the seriesly connected transistors which can be switched off without danger of destroying have been developed by author after priority date during 2001÷2004.